STRIATIONS IN THE POSITIVE COLUMN OF AN ARGON GLOW DISCHARGE

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the requirements for the degree of

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IN
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ABSTRACT

An investigation was conducted of the effects of probes and external circuitry on characteristics of medium pressure argon glow direct current discharge. The conclusions of previous investigators, that the cathode has greater influence than the anode on the discharge characteristics, was substantiated. Evidence that hysteresis is transient and varies directly as stabilizing cathode temperature was obtained with consequent elimination of multiplicity of modes in steady state operation.

It was observed that striations moving towards the cathode increase in velocity between standing striations and have a minimum velocity within the standing striation. There appeared to be a phase difference which varied with distance from the cathode of 7 to 10 microseconds between spectrum lines 4159-4164 Å and 6965 Å with the higher energy line leading.

The effect of varying the isolating resistor was much greater than anticipated. In some instances regions of operation with standing striations appeared and disappeared randomly. In particular, with load resistances greater than one megohm, a mode was established with peak to peak voltages of 400 volts, superimposed on the d.c. voltage across the tube. Striations previously termed moving appeared in this mode to be pulsating at fixed position or to have velocities greater than the available equipment could measure. Removal of probes from the discharge path had little effect on operating characteristics.

The writers wish to express their appreciation to Professor N.L. Oleson and other members of the Physics Department for their inspiration, counsel and generous assistance.

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INTRODUCTION

1. The Glow Discharge

The application of voltage across electrodes contained in a gas filled tube will result in current flow. If the applied voltage is below the breakdown potential a small current of the order of 10^{-12} amp is observed. Breakdown voltage is a function of tube geometry and gas pressure. If the applied voltage is equal to or greater than the breakdown potential a marked increase in current will be observed, accompanied by a characteristic glow. Once initiated, a glow will persist at voltages less than the breakdown voltage.

If the gas pressure is of the order of atmospheric, the discharge will appear as a torturous spark. If the pressure is reduced, the path of the spark will become first less torturous and then diffuse until, at a pressure of approximately 1 cm Hg. the glow will fill the entire tube. At pressures of 1 to 10 mm Hg. the region of interest in this investigation, the tube will no longer be uniform but have the appearance illustrated in Fig. 1.

2. History

Many studies have been made of direct current glow discharges in noble gases. Early observers concluded that in the simplest case, the positive column is homogenous, and the current is constant. Aston and Kicuchi (1921) studied moving striations in an intermittant discharge and Kicuchi subsequently used a direct current source. These investigators utilized a mirror rotating on an axis parallel with the discharge tube. In contradiction to previously accepted homogeneity striations were observed to move toward the cathode. Mean velocities

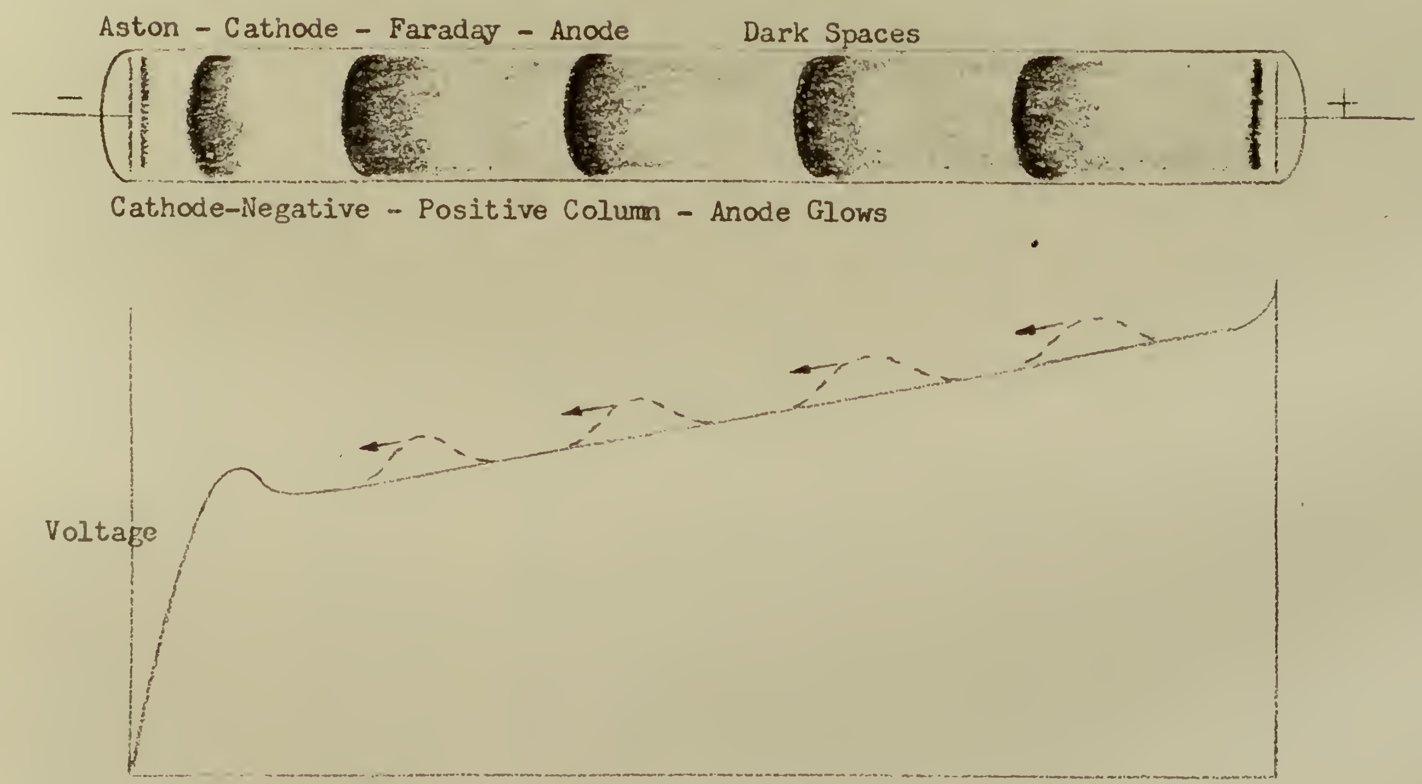


Fig. 1 - Regions of Typical Striated Column with Corresponding Voltage Distribution

were reported to vary inversely with the square root of the pressure and inversely with tube radius. Velocity also fluctuated in travel and was specific for a specific distance from the cathode. Subsequent investigations, using the already mentioned rotating mirror technique, probe measurement techniques and photo-multiplier-oscilloscope techniques, have led to the conclusion that striations in a glow discharge are the rule rather than the exception and it is quite likely that any theory of discharges which neglects these moving striations is defective in some essential way (1,2,3,4). The literature most frequently refers to cathode moving striations as positive striations and anode moving striations as negative striations. A mode is said to exist when the frequency of the moving striations varies continuously with current. Boundaries, then, consist of frequency discontinuities. In the current investigation standing striations occurred when moving striations were not random. Thus, while standing striations are not necessary for the existence of a mode, a mode did exist whenever standing striations appeared. A summary of observations and conclusions pertinent to the writers' investigation follows.

a. Glow discharges in the rare gases having an apparently uniformly luminous positive column are a source of stable audio frequency oscillations (5).

b. The velocity of the striations is always of the same order of magnitude as the axial velocity of the positive ions, namely mX (where m is the mobility of the positive ions and X is the voltage gradient) (6,7,8,9,10).

c. Probe measurements have shown that the voltage gradient, the electron temperature and the electron concentration are not constant,

but change in phase periodically as the striations pass a particular point in the discharge tube (8).

d. During one period the column current changes by only about 1% and voltage oscillations range from 5 to 20 volts rms (1,2,3,4,8,27).

e. Standing striations usually appear dense on the cathode side and diffuse on the anode side. The dense portion of the striation has a radius of curvature on the anode side.

f. An increase in brightness occurs on the anode side of a probe (12,27).

g. Multiplicity of modes, that is, more than one pattern of standing striations for a given current, has been reported by some observers (1,2,3,4,12).

h. Hysteresis has been noted by a number of investigators (12,13,14). By hysteresis is meant a variation in steady state of tube voltage for a given current depending on past discharge history.

3. Theory

While much quantitative empirical information concerning the processes involved in glow discharges has been published, analytic solutions require simplifying assumptions which frequently are not representative of actual conditions. In particular, the positive column remains an important area for investigation. Its behaviour, despite a uniform appearance, is far from simple.

It is well established that the gas temperature of the positive column is quite low, indicating that thermal ionization cannot be a factor in the conductance of the column in the glow discharge. The column is a typical plasma having equal concentrations of positive ions and of negative ions and electrons. The temperature of the positive ions is somewhat higher than the gas temperature, and the electron

temperature is very high. Measured values of the reduced field (electric field/gas pressure) in the positive column (15) show that the voltage gradient increases if tube radius is decreased. This result is due to the greater loss of ions to the tube walls requiring an increase in the ionization processes established by the electric field (16).

It is appropriate to consider first the theory of Donahue and Dieke (1,2,3,4) because all subsequent significant investigations take cognizance of their work. They reported, in addition to the more frequently observed cathode moving striations, much faster anode moving striations of smaller amplitude which were termed negative striations. They state that in the region of the negative glow and Faraday dark space the space charge changes to negative. The resulting axial voltage distribution is illustrated qualitatively in Fig. 2. The voltage peak in the vicinity of the negative glow is an electron trap. Unless electron diffusion is sufficient to maintain a steady current, the negative space charge will increase in dimension, decreasing the cathode fall and eventually extinguishing the tube. The discharge would not die, however, and the current would rise again if there is a means of removing excess electrons. The cathode moving striations, regions of positive ion concentration which approach the electron trap, act in such a way. An approach, the field is at least partially reversed and a number of electrons are attracted toward the striation (bow termed positive striation). When this happens the cathode fall and current increase. The escaping electrons constitute the negative striations. When the positive and negative striations meet, they are both trapped for periods in the order of 10 microseconds. While the specific

ionization is least in this trap, the time involved is relatively large resulting in the visible standing striation. This trap is relieved by the subsequent positive striation approaching in the same manner that the electron trap in the negative glow was relieved. The process then is continued throughout the positive column. Eventually each negative striation will reach the anode and in falling in the strong field close to the anode will acquire sufficient energy to produce a new group of positive ions. This becomes a new positive striation and travels toward the cathode to complete the process.

Few observers other than Dieke and Donahue have reported negative striations. Karge, Hooks and Oleson found evidence of negative striations at the beginning of the positive column, but associated them with decreases in light intensity which they labelled 'antipeaks'. (14). Also Foulds (29) found evidence of negative striations in mercury vapor. A. A. Zaitsov (17) reported anodal moving striations which he attributed to the oscillation of the head of the positive column.

G. V. Gordeev (17) finds the hypothesis of Donahue and Dieke unsatisfactory because of the intimate connection of the positive striations with the motion of ions. He believes both positive and negative striations to be the direct result of electron activity. His conclusion is that striae are a wave group initiated by grouped electrons striking the anode. Negative striae he deems to be reflections of the positive straie from the cathode. The electrons are grouped by the straie to complete the cyclic process.

It is appropriate here to consider attempts to explain features of moving striations in terms of plasma oscillations, first proposed by Tonks and Langmuir (11). Such attempts assume the existence of an

ionized plasma, or interacting ion streams each satisfying a continuity equation, and proceed on the basis of small perturbations to arrive at a dispersion relationship for ion density waves traveling in a medium. The desired result is the possibility that a small perturbation will not necessarily remain small.

Watanabe and Oleson (18) treated the problem of striations as a problem in coupled continuity equations; the continuity equations for electrons and ions within the plasma. Basic assumptions are that electron and positive ion energy distributions are Maxwellian, that the ambipolar equation (19) applies and that the number of ion pairs created per unit time per electron is constant.

Walsh (20), utilizing the approach of Watanabe and Oleson with the exception of their treatment of diffusion of electrons and ions to the side walls, shows that all of the characteristics of the striations are due solely to the non-linearities in the continuity equations and to the variation in the electron parameters due to the change in electron energy throughout the striation. The power balance equation is then introduced to determine the change in electron energy.

Robertson (21), from a theoretical examination of the ion balance equations for a plasma shows that a homogeneous plasma is not always possible. When ionization proceeds by a two stage process involving accumulated metastable excited atoms, as may be the case in noble gases, small perturbations of the ion concentrations from their equilibrium values may not remain small. Under such conditions a spatially uniform steady plasma cannot exist.

An excellent review of theories involving ionization wave theory and plasma-ion wave theory with combustion wave analogy concepts, is contained in the thesis of Farris (22).

CHAPTER II

APPARATUS AND EXPERIMENTAL TECHNIQUES

1. General

The apparatus and experimental techniques employed in this study were basically similar to those used at the U.S. Naval Postgraduate School by Pigg and Burton (12). Numerous improvements and variations were made, however, and to provide for continuity a brief description of the equipment and procedures is included.

Fig. 2 is an overall schematic of the experimental set up. It is divided into sections which are individually discussed in the following paragraphs.

2. Discharge Tubes

Details of the discharge tube used for the major portions of the experiment are shown in Fig. 3. A photograph of the discharge tube with the probes removed is included as Fig. 4. A notable feature is the availability of the several possible combinations of cathode and anode. The molybdenum electrode consisted of an arrangement of four fins and had the relatively large area of at least 65 sq. cm. The zirconium electrodes were solid right cylinders having an area of approximately 5 sq. cm. The tungsten electrode was originally as pictured in Fig. 2, but had been damaged prior to use for this investigation. With only a small portion of the original 10 mil wire remaining, the tungsten electrode was much smaller than the zirconium electrode.

The center portion of the tube containing the five probes shown in Fig. 3 was removed late in the experiment and replaced with a smooth cylinder of about the same dimensions. No field or concentration measurements requiring the use of probes were made.

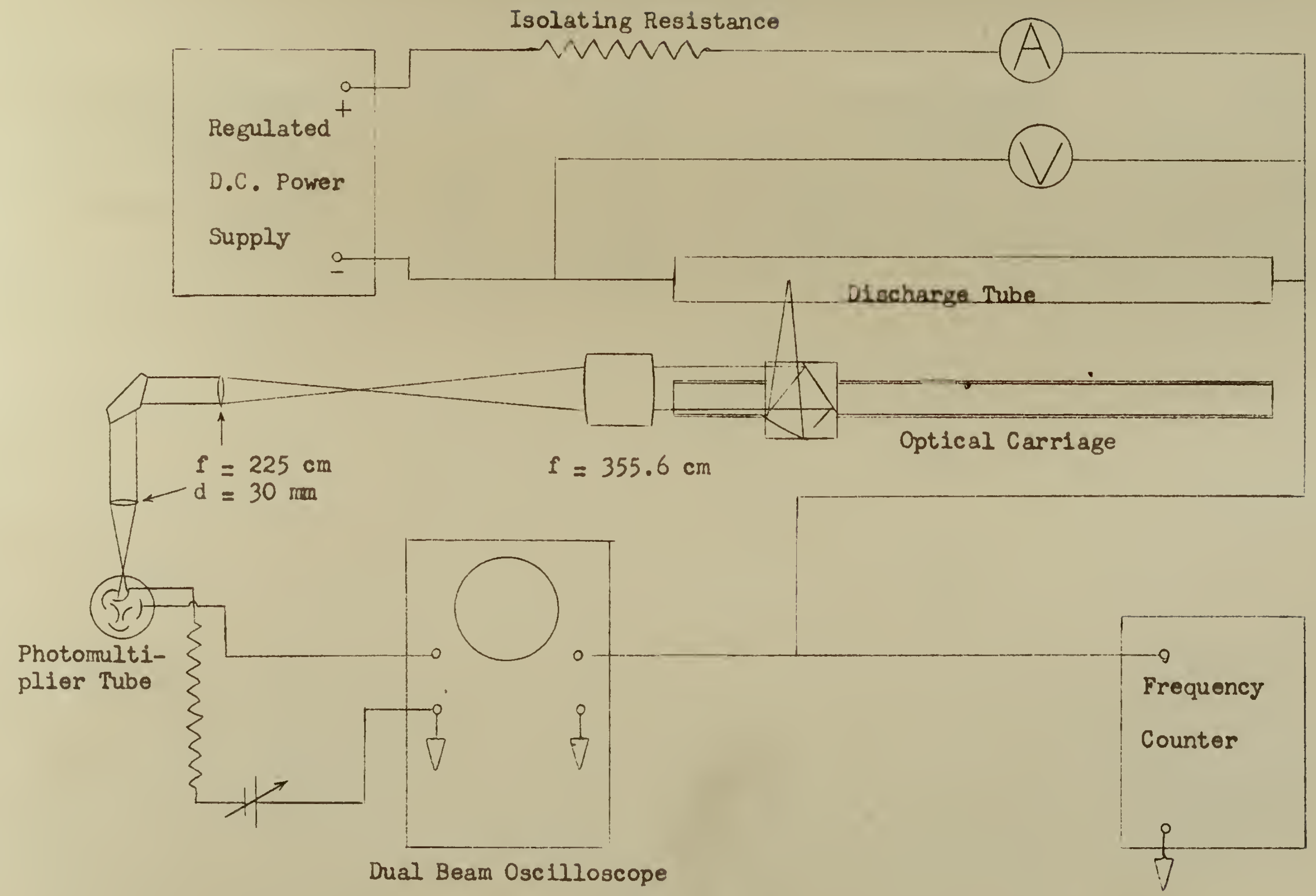
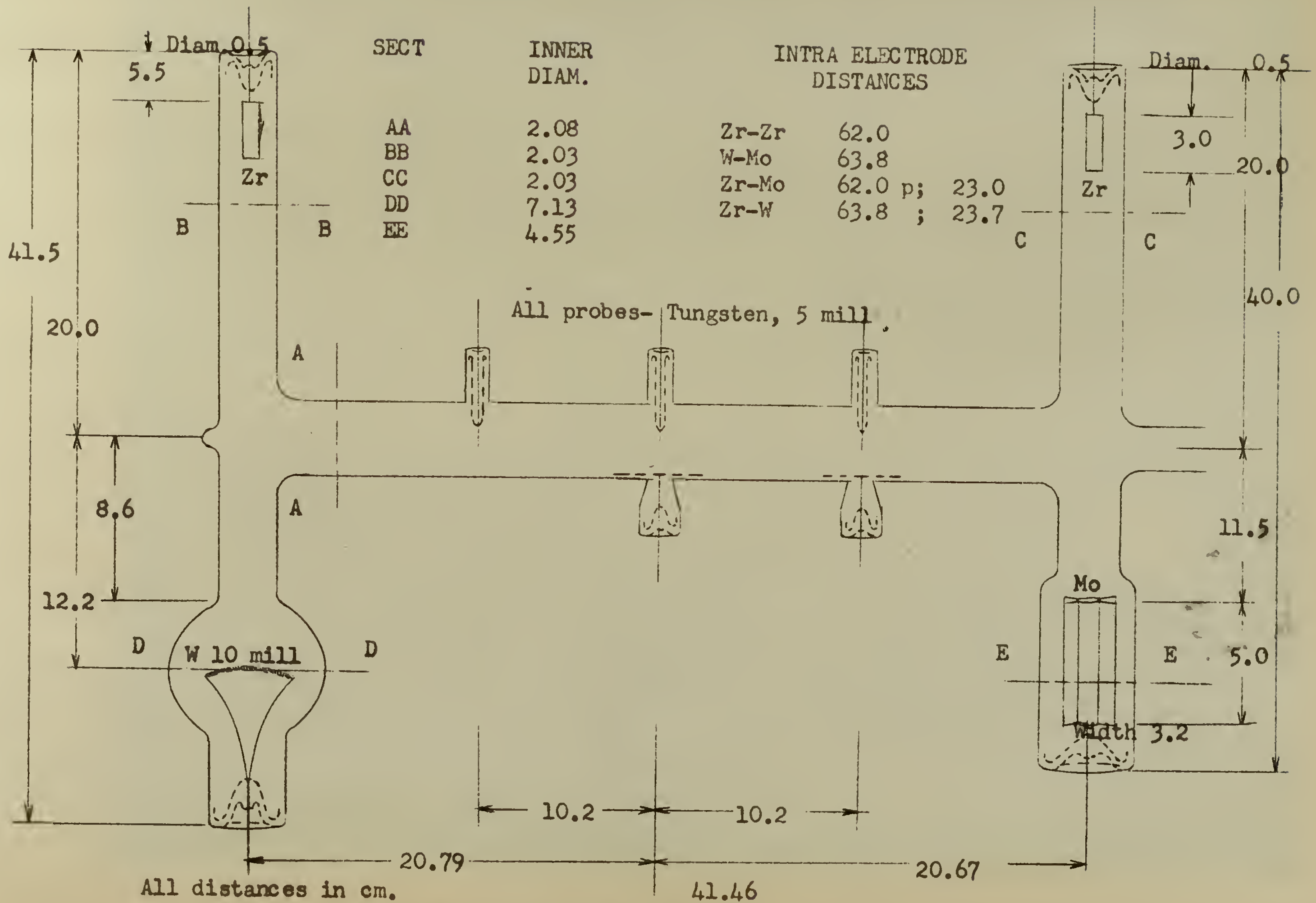


Fig. 2 - Overall Schematic of Experimental Apparatus



All distances in cm.

Fig. 3 - Details of Discharge Tube

The tube was mounted horizontally as shown in Fig. 4 and was connected to a high vacuum system through an Alpert valve (23).

3. Vacuum and Filling System

The vacuum system, as shown in Fig. 5, was simple in construction and provided an ultimate vacuum of 5×10^{-8} mm as measured with a VG-1 A ion tube and Type DPA-38 Ionization Gauge, Consolidated Vacuum Corp. Filling was accomplished in the manner evident from an inspection of Fig. 5 with the desired operating pressure observed on an oil manometer.

4. Purity of Discharge Gas

Considerable time and effort was made to ensure the freedom of the system from impurities. The following were considerations and techniques employed:

a. All stopcocks were greased with Apiezon N which has a room temperature vapor pressure of 10^{-8} to 10^{-9} mm of Hg.

b. Manometer and diffusion pump oil was Octoil-S which has a room temperature vapor pressure of 5×10^{-9} mm of Hg.

c. The discharge tube, the Alpert valve, and the tubing leading to the liquid air trap marked #1 in Fig. 5 were degassed by baking for several hours above 400°C.

d. All electrodes were degassed by use of an induction heater followid by positive ion bombardment, in the presence of Argon, using a high voltage alternating source.

e. The entire system was flamed using normal techniques.

f. Linde high purity mass spectrometer controlled argon gas was fed through a liquid air trap at a very low rate to the discharge tube. Excellent rate control was provided by the Alpert valve, and about a ten-minute filling time was used.

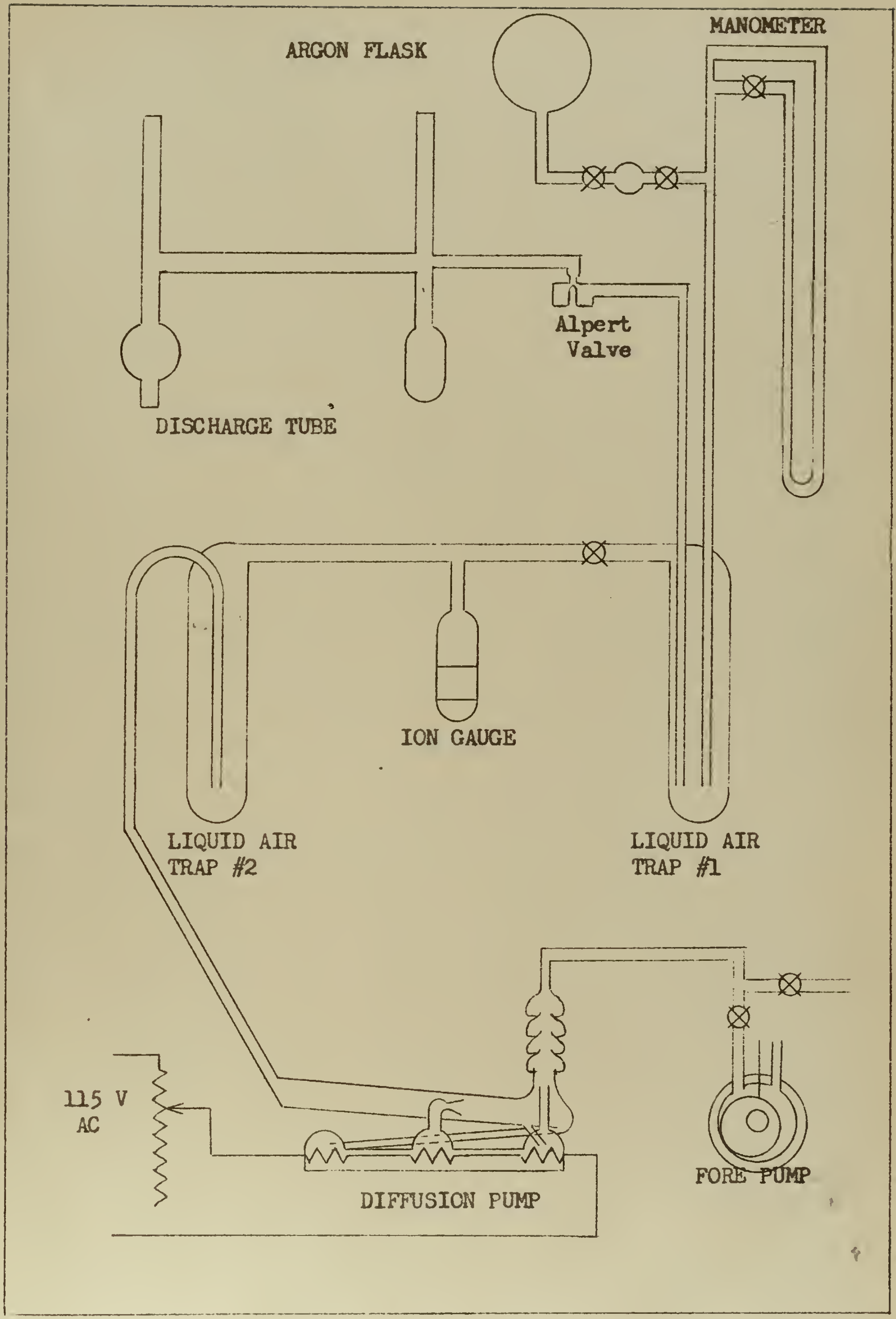


Fig. 5 - Diagram of Vacuum System

g. The discharge tube was isolated from the remainder of the vacuum system by means of an Alpert valve, as previously described, and the remainder of the system maintained at high vacuum. As a final purity check, a spectrographic analysis was made of the gas in the discharge tube after operation for two weeks. A Gaertner Spectrograph and a photographic plate with Helium comparison source was used. Careful analysis showed no tracer of impurities.

5. Optical System and Photography

Light from any point in the horizontal column could be focused on a photo multiplier tube as can be seen from inspection of Fig. 2. A Gaertner Precision Wave Length Spectrometer was used as shown to select specific spectral lines. The signal-to-noise ratio of the RCA 1P21 Phototube was increased considerably by surrounding the tube with liquid air in addition to employing the techniques recommended by the manufacturer. The sensitivity of the entire optical system is shown in Fig. 6. A tungsten filament lamp source emitting at 2870°K (as measured by an optical pyrometer, the light intensity indications on an oscilloscope, and the energy-wave length curve for tungsten at this temperature (24) were utilized to produce this curve. The useful limits proved restrictive and made a careful inspection for any possible light loss a necessity. The output of the photo tube was displayed on dual-beam oscilloscope, as was the voltage across the tube. Using double exposure technique (keeping the voltage trace on for control), light intensity traces of two separate wave lengths could be recorded. Examples of these photographs are shown in Fig. 7.

In addition to the scope photography normally employed, a technique was devised to provide for quantitative measurements of the

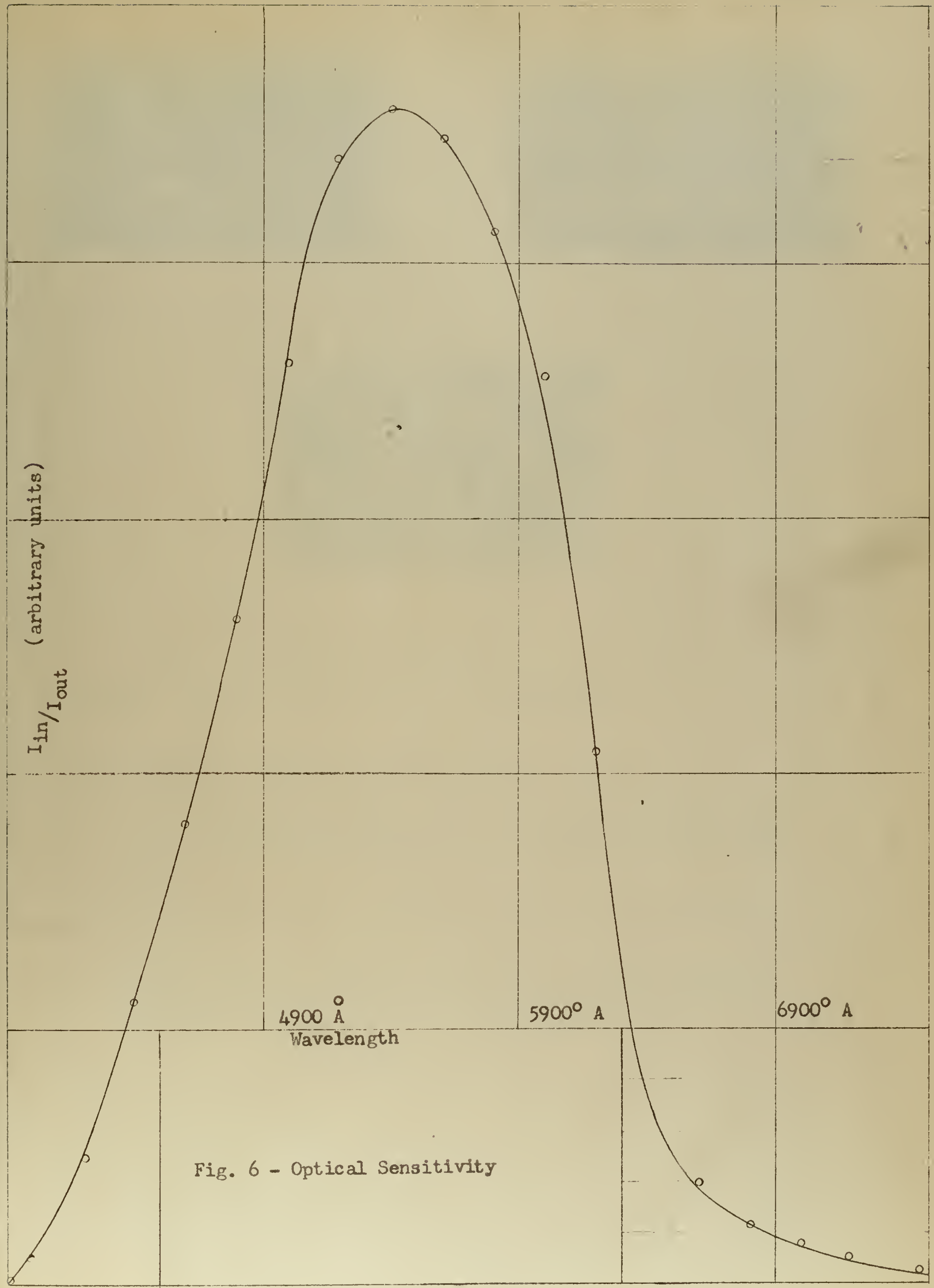
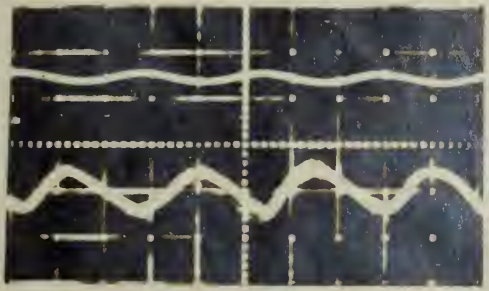


Fig. 6 - Optical Sensitivity



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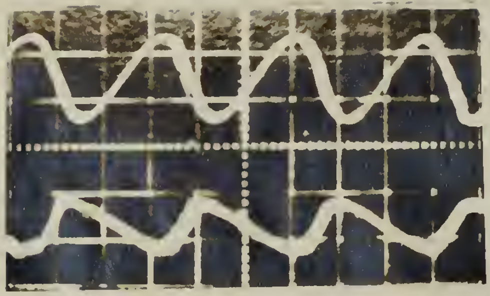

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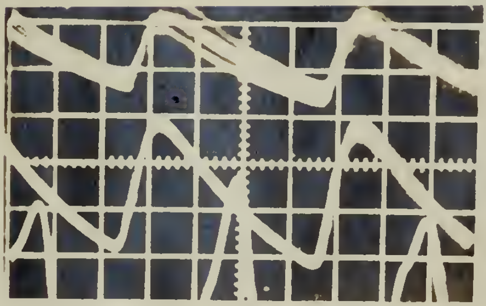


C

Fig. 7 - Oscilloscope Photographs

Vertical and Horizontal Grid Lines each Centimeter.

Zr Cathode, No anode, 62 cm Path, Argon at 2 mm Hg.

A. 2.4 plus milliamps. Upper trace is voltage across tube at 200 volts per cm amplitude and sweep of .2 ms per cm. Lower trace is Photo tube OUTPUT with same sweep and amplitude of .2 volts per cm.

B. 2.4 minus milliamps. Now in Anomolous mode. All settings as in A.

C. Example of photo-recording of data for motion and phase relationship curves. Upper trace is 6965°A. Middle trace is 4159-4164°A. Lower trace shows voltage peaks.

positions and movements of the standing striations. An illuminated graticule was simply positioned in front of the portion of the tube to be photographed. By proper adjustment of graticule brilliance and exposure time, excellent results can be obtained over the complete range of tube currents available.

6. Circuitry and Instrumentation

The schematic circuit diagram utilized to check the phase and velocity relationships reported by Pigg and Burton (12) is shown in Fig. 2. Fig. 8 shows the schematic used to observe the discharge at very large values of resistance. Points of notable interest are:

a. Power was limited for the most part by the DC supply to one thousand volts. Peak to peak AC as measured directly across the power supply output was less than .01 volts.

b. For observations at very large values of resistance, several batteries were utilized in series with the normal supply to provide a total of 1400 volts DC.

c. Variable resistors were chosen with large power ratings to keep their temperature effects negligible. Where the current would permit, the wire wound resistors were replaced with carbon ones to check on possible inductance effect.

d. Power for the photo-multiplier tube was furnished by a locally manufactured system including on its impact side a constant voltage transformer.

e. The frequency counter which was triggered by the oscillations in tube voltage provided instantaneous indication of either the frequency or period. For some complicated voltage forms it was necessary to check this indication by displaying the output of a signal generator on the oscilloscope in place of the light intensity trace.

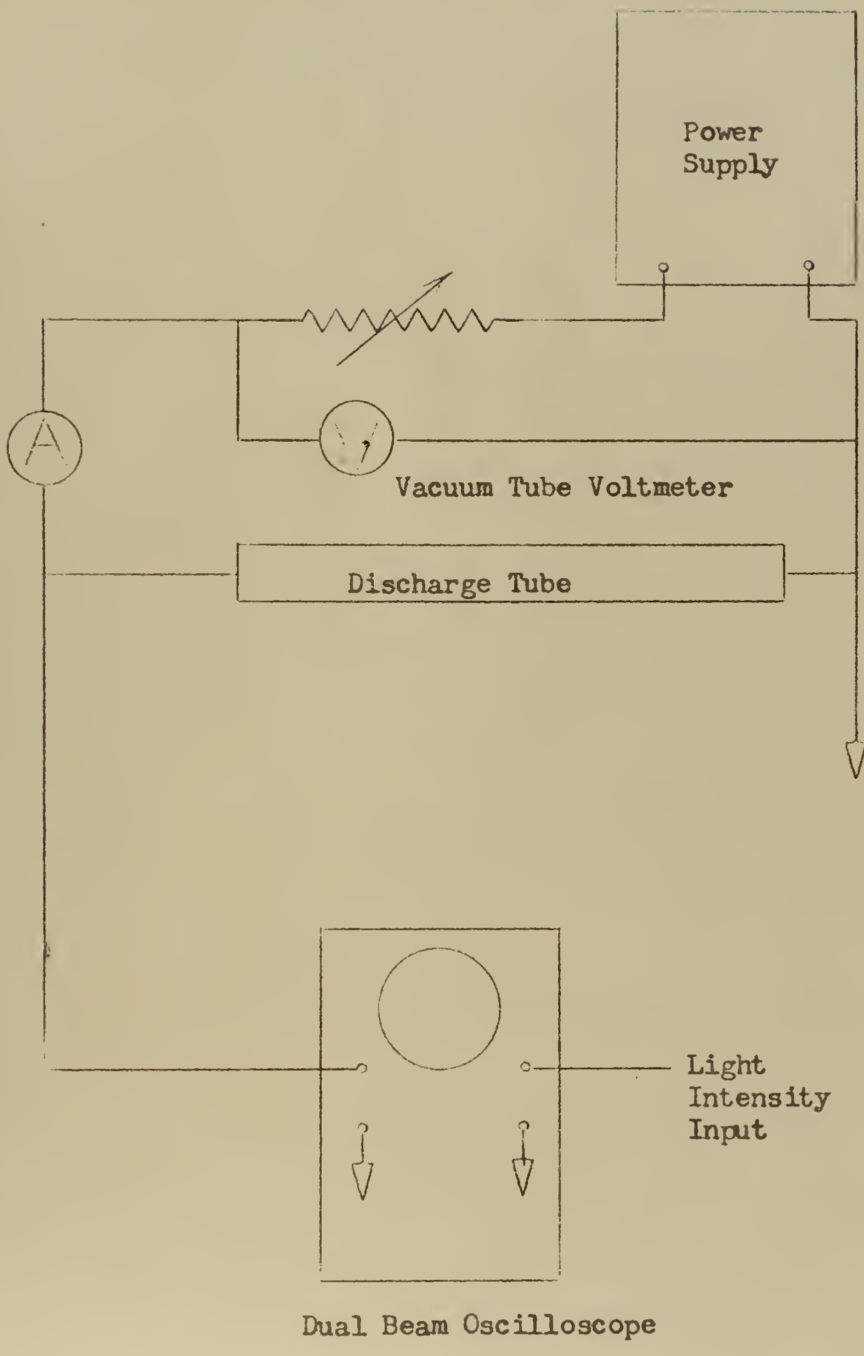


Fig. 8 - Electrical Circuit

f. Both sweeps of the dual beam oscilloscope were triggered externally by the oscillations in the tube voltage.

g. Three vacuum tube volt meters were available for obtaining RMS values and were used exclusively during investigations at large values of resistance.

7. List of Equipment

Dual Beam Cathode Ray Oscillograph, Dumont Type 322-A, replaced by

Dual Beam Cathode Ray Oscillograph, Hewlett-Packard Model 150A

Frequency Counter, Hewlett-Packard Model 524A.

Oscillograph-Record Camera, Dumont Type 295 (for scope photos)

Oscillo-Record Camera, Fairchild Model F246A (for tube photos).

Test Oscillator, Hewlett-Packard Model 650A.

Voltmeter 20,000 Ohms per Volt, Weston Electrical Instrument Co.

Ammeter, Weston Electrical Instrument Co. Model 931.

Vacuum Tube Voltmeters, Hewlett-Packard Model 410B.

Precision Wave Length Spectrometer, Gaertner Model L234.

Multiplier Phototube, RCA 1P21.

Phototube Power Supply, Locally assembled with constant voltage transformer input.

Power Supply, Voltage Regulator, Kepco Labs Model 1250B.

Batteries, Super Heavy Duty "B", Burgess Battery Company.

Fore-Pump, Central Scientific Company, Model HYVAC 7.

Diffusion Pump, 2 Stage, Air colled, Consolidated Vacuum Corp. Type GF-25A

Pirani Gauge, Distillation Products Ind. Type PG-1A.

Ionization Gauge, Consolidated Vacuum Corp. Type DPA-38 with VG-1A ion tube.

Induction Heater, Scientific Electric Company, Model AC-5-LB.

Enlarger, Dejur USA, Versatile.

Various other components and sundries all chosen for quality and reliability.

CHAPTER III

OBSERVATIONS AND ANALYSIS

1. Effect of Standing Striation on Velocity of Moving Striation

Velocities of the positive striations were in agreement with those reported previously in two mm Hg of Argon (1,12,13,14). The average velocity at 29 ma was about 200 meters per second, with a maximum of 310m/sec and a minimum of 110 m/sec.

An observation of the change in velocities of moving striations in their passage through standing striation was made using monochromatic light in the 4159-4164Å range. The circuitry for this observation is shown in Fig. 2. The portion of the discharge tube between 21 cm and 31 cm from the cathode was situated between two probes, the left edge of this section being at one of these probes. Two stationary, or standing striations were observable in this area. The positions of these standing striations is as indicated in Fig. 9. Also shown are the results of the analysis of many scope photographs obtained utilizing procedures identical to those of Pigg and Burton. The behavior of a positive striation seemed to show that its velocity was greatest between standing striations and least at the position of the standing striations which manifests itself by a maximum of observable light intensity. An exception occurred however, in that the velocity appeared to continue to decrease after passing the standing striation closest to the probe. This could be due to a repulsion caused by the positive ion sheath surrounding the insulated probe. Indicated in Fig. 9 is the resultant velocity distribution of the moving striations as observed.

Donahue and Dieke postulated in their theory that the velocity of the moving striations falls to zero at the positions of the standing

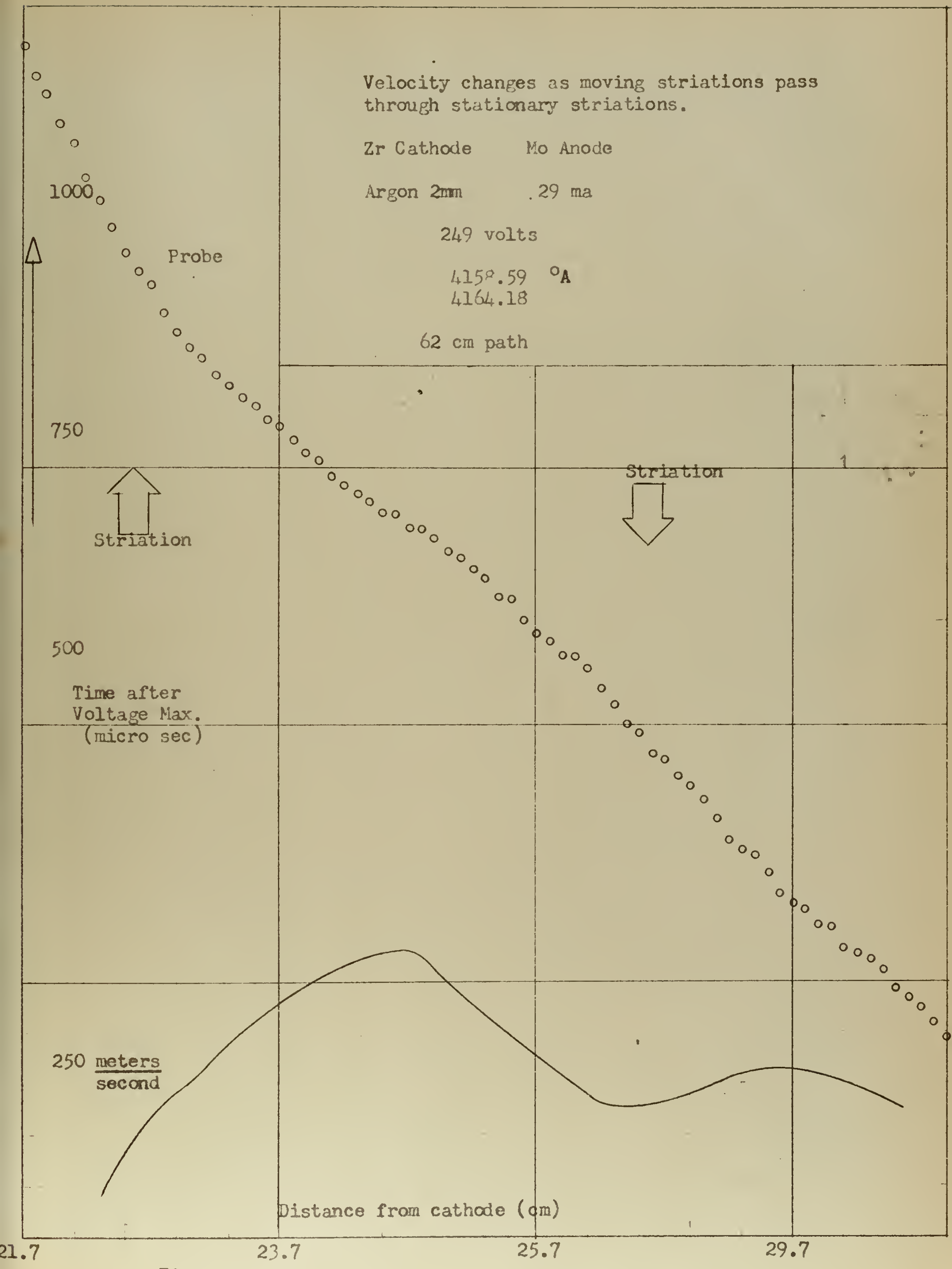


Fig. 9 - Velocity Plot

striations and remains at zero for short periods. They also reported that the light intensity reached a zero value somewhere between striations. Neither of these effects were observed, however the construction of tubes was not similar and as can be seen in Fig. 9, it is possible that the velocity of the striations fell to zero for intervals of 10 microseconds between experimental points.

2. Phase Relationships

A brief investigation of the phase relationship existing between two light wavelengths was made in an attempt to verify a result previously reported by Pigg and Burton (12). In contradiction to Kolkhorst and Strong (13) working with argon, and Donahue and Dieke (1) working with mercury, Pigg and Burton reported that some lines of higher energy lead other lines with a lower excitation potential difference.

The schematic circuit diagram utilized to verify this relationship is shown in Fig. 2. Using the technique of double exposure scope photography as mentioned in Section II-5, photographs were obtained similar to those shown in Fig. 8. Time differences were measured between corresponding peaks of light intensity. The wave lengths chosen were 4159-4164 Å and 6965 Å. These lines were preferred because:

a. Relative intensities are large (25).

b. Transitions are to the same energy level.

c. These wavelengths were the most widely separated in the useful spectrum range.

Analysis of the photographs produced the plot shown in Fig. 10. This plot covers only the length of the discharge tube between 21 cm and 31 cm from the cathode and each point is an average of two observations. As can be seen in Fig. 11 the error in measurements is large,

Distance between 4158°A line (leading) and 6965°A line in microseconds.

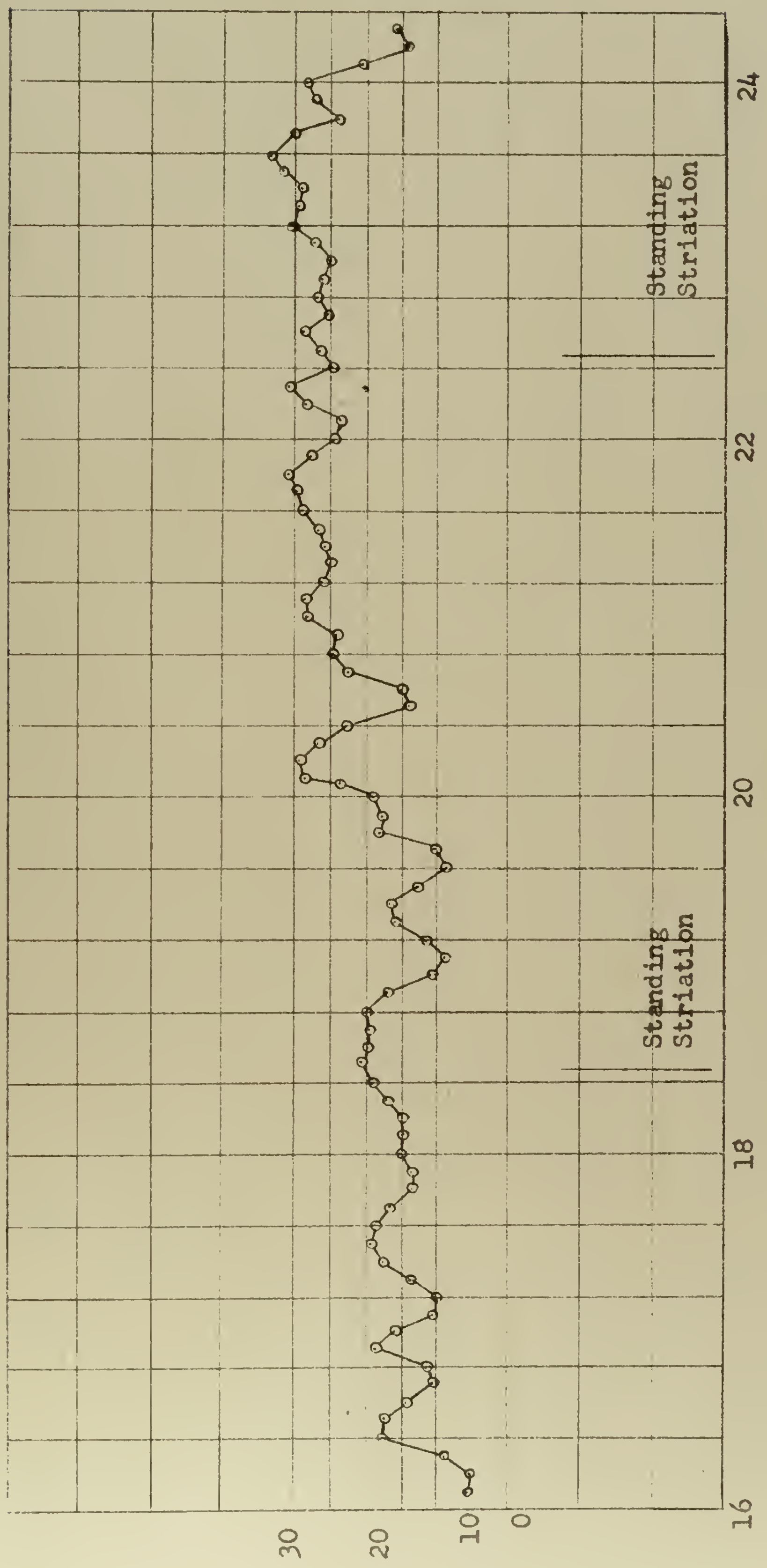


Fig. 10 - Phase Relationship

approximately 3 microseconds, however, indications are that there is a phase difference between the lines of about 7 microseconds at the cathode side of the region and that this phase difference increases to about 10 microseconds at the anode side. Furthermore, in agreement with Pigg and Burton it is evident that the higher energy line precedes the lower energy line throughout this region.

3. Hysteresis and Multiplicity of Modes

That the path followed by the voltage as the current is reduced is, at equilibrium, different from that along which it rises has been termed hysteresis. Hysteresis has been mentioned previously, but not always with the same meaning. The present discussion of hysteresis is limited as defined above. Apparently due to this effect, multiplicity of modes has also been reported. By this is meant more than one mode existing for a given current, depending on the past history of the discharge.

The circuitry used to investigate these effects is shown in Fig. 2 and an example of a hysteresis curve with attending multiplicity of modes is shown in Fig. 11. Curves similar in shape but enclosing more or less area were obtainable, however not in steady state. Rather, it was observed that the area enclosed by the voltage current loop was a function of time. That is, if changes in current were made in small increments, with long waiting periods between changes, the bounded area became vanishingly small.

In an attempt to explain the reason for a time dependence, the temperature of the lead in wire to one of the zirconium electrodes was measured with a thermocouple. It is felt that this method gave at least an indication of the tendency of actual cathode temperatures. A

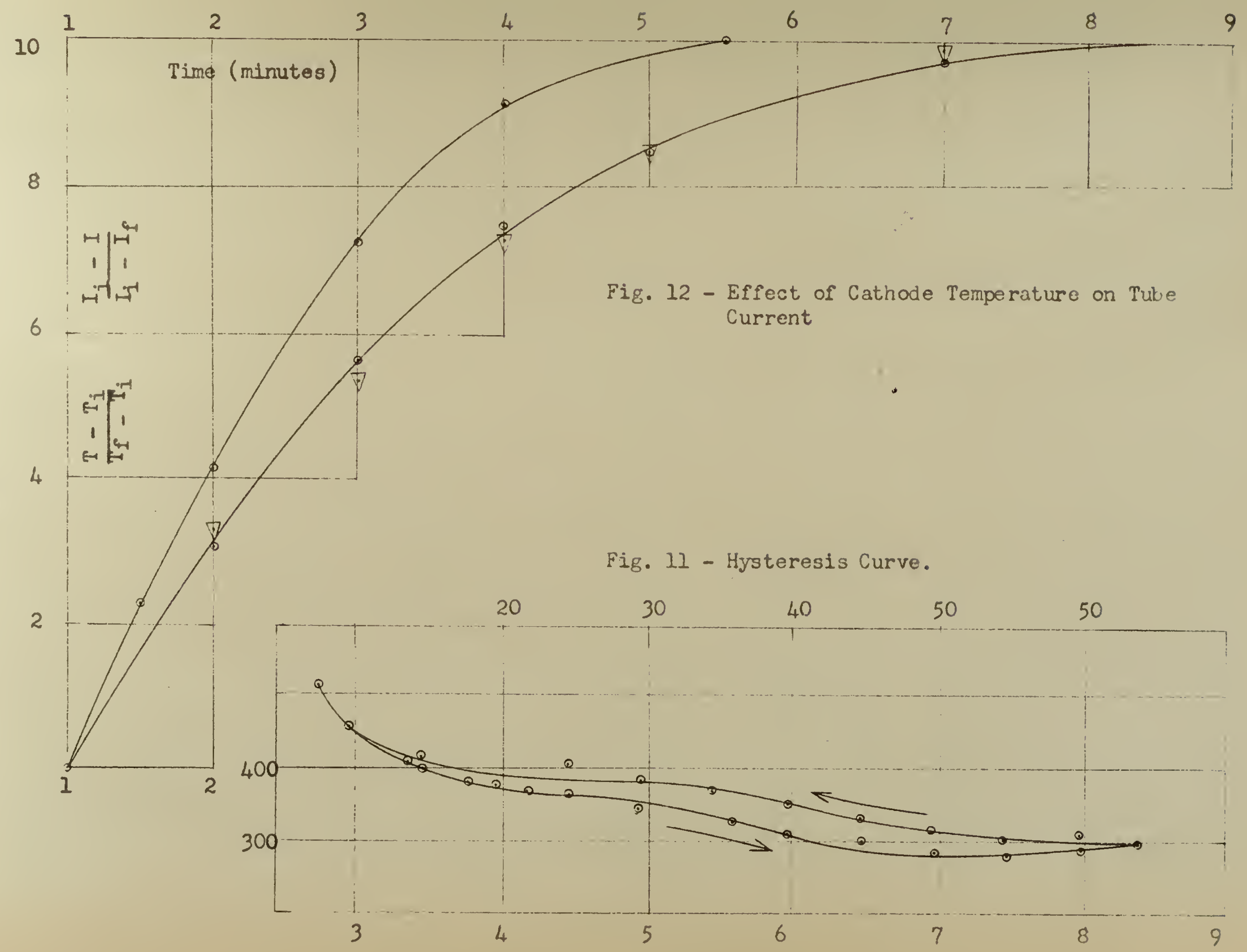


Fig. 12 - Effect of Cathode Temperature on Tube Current

Fig. 11 - Hysteresis Curve.

plot of reduced temperature and reduced current versus time produced essentially the same curve, as is shown in Fig. 12, following a relatively large current change. A similar plot without temperature measurements is also shown for the tungsten electrode. Using the molybdenum as cathode, no current changes were noted under the same conditions. This can be explained by noting the very large area of the molybdenum electrode. As is shown in a voltage current curve by Pigg and Burton (12), using this same molybdenum electrode as cathode no hysteresis was observed.

The conclusions to be drawn here are that at equilibrium:

a. There is one mode for a given current and regardless of direction of approach or past history, the resultant tube voltage will be identical.

b. The hysteresis effect as herein defined does not exist if sufficient time is allowed between readings for the cathode region to come to equilibrium temperature.

4. External Circuitry

Karge, Hooks, and Oleson (14) reported that, for the tube used in their investigation, use of isolating resistances outside the range 10,000-15,000 ohms resulted in instability. Donahue and Dieke (1) reported that electrode current fluctuations are identical, except in amplitude, for any permissible values of external resistance at anode and cathode, and that electrode currents vary in such a way as to keep the magnitude of the voltage oscillations constant at peak to peak values approximately equal to the excitation potentials of the gas. As was suggested by Karge, Hooks and Oleson, it was decided to determine what effects external lumped constants have on the discharge tube under study.

The initial step was to remove all lumped constants not essential to operation and to observe the effect of changing tube current. At the head of the positive column was a bright ball which did not fluctuate in steady current operation as reported by some observers. The column length did change with current change; the head moved away from the cathode with increased current. The total variation is of the order of 10 mm, almost all of which occurred during current change from 5 to 40 ma. Currents above 40 ma caused little further movement; changing from 40 to 70 ma resulted in only about 2.0 mm additional decrease of the positive column. This change of column length with current was independent of path, anode material, and whether or not the tube was in a stable mode.

Changing path length had the expected effect of changing the length of the positive column. This change, with the change in tube voltage, indicates that the average field in the positive column was 2.25 volts per centimeter at 20 ma, which is in agreement with accepted values (15), although the instantaneous field would be widely different from this value.

Fig. 13 and pictures contained in Fig. 14 show that there is one mode or several contiguous modes in the area between 14 and 18 ma. This afforded a means of investigating the movement of standing striations with changing current. The results are plotted in Fig. 15. The merging of two striations into one at about 15 ma is of particular interest. Fig. 13 was obtained by varying the isolating resistance as indicated in Fig. 2 with no isolating resistance the discharge ceased at 63 ma. No stable modes existed above that indicated at 25 to 29 ma. It is obvious that external resistance cannot be zero if an a.c. voltage

is to be generated. The effect of the isolating resistance is greater than this non-zero requirement, however. That the existence of stable modes should require particular values of resistance in random fashion as well as particular current values is presently inexplicable.

No effect was noted in establishing ground at different points in the circuit. Inserting a capacitor in parallel with the isolating resistance had the effect of a resistance equivalent to the parallel impedance. It was noted, however, that connecting the frequency counter with a 750 uuf capacitor caused small changes in voltage amplitude. Such change did not invariably occur in each cycle but sometimes alternately, or in every third or fourth cycle. The Hewlett-Packard Model 524A frequency counter had an input impedance of 500,000 ohms, and as is evident from the resulting time constant this effect is an ever present consideration. When working with relatively small isolating resistances and using a 4 uf capacitor this effect was not as evident. For this particular case, since the period is not effected, we found it advantagous to eliminate the counter except for brief intervals as necessary to record frequencies. Similar consideration was given to other possible sources of capacitive effect.

5. Anomalous Mode Characteristics

In an attempt to complete the operating envelope mentioned in the preceding paragraphs, and shown graphically for values up to 100,000 ohms in Fig. 13, it was necessary to use very large values of resistance (over 1 Meg Ohm). Analysis of the discharge at these very large values of external resistances was accomplished using circuitry as indicated in Fig. 8. It was noted that the same modes existed as previously but, as was expected, the peak to peak AC oscillations of the tube voltage

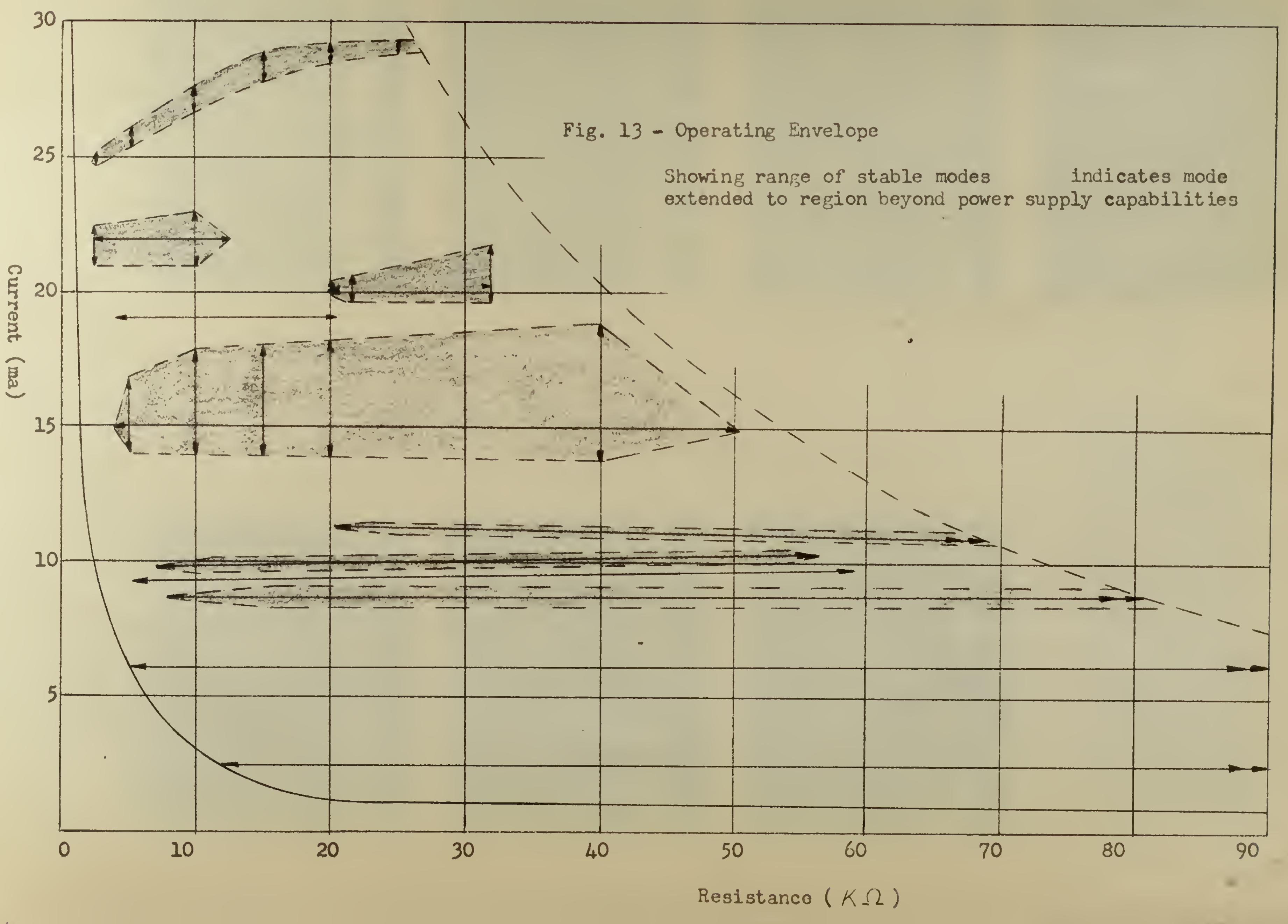
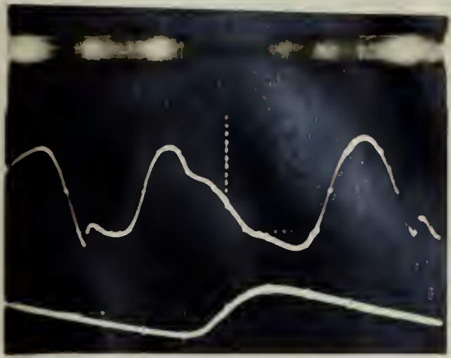


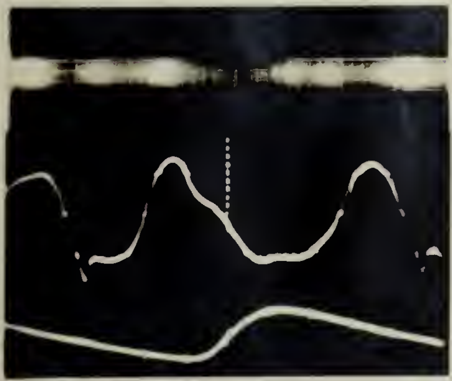
Fig. 13 - Operating Envelope

Showing range of stable modes   indicates mode extended to region beyond power supply capabilities



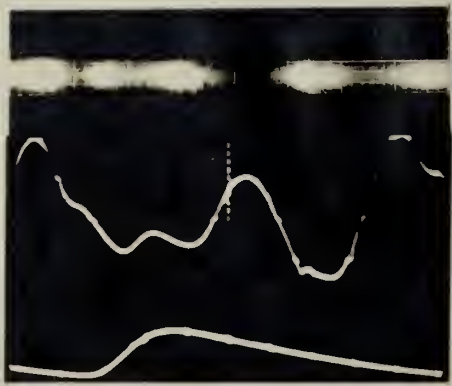
14 ma

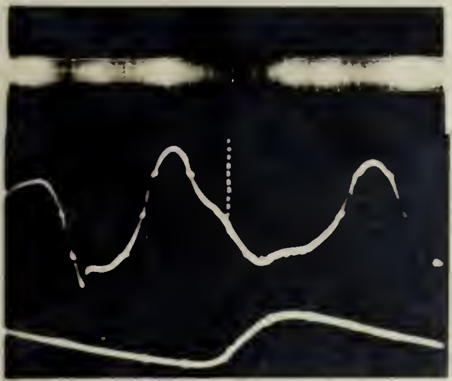
A sequence showing striations in a 10 cm section, containing a probe, as current is increased from 14 ma to 17 ma. UPPER trace is voltage across tube. At 14 ma, Peak to Peak voltage is 55 volts. Period is .4 ms. Lower trace is light intensity. Probe is .56 cm to right of center.



14.5 ma

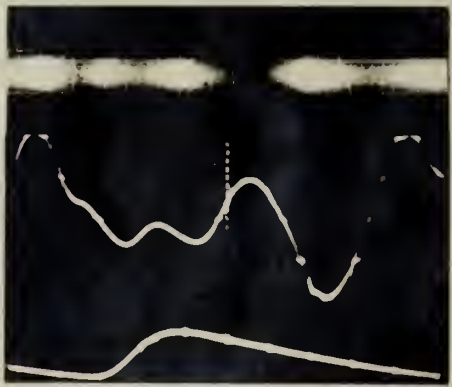
16 ma

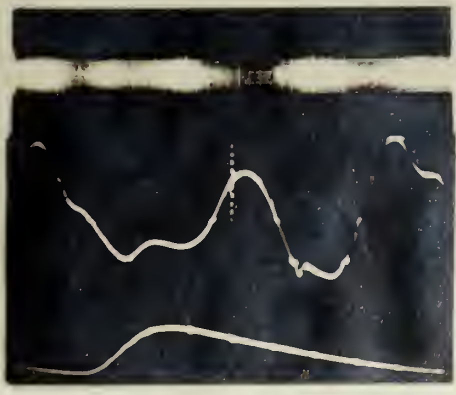




15 ma

16.5 ma





15.5 ma

17 ma

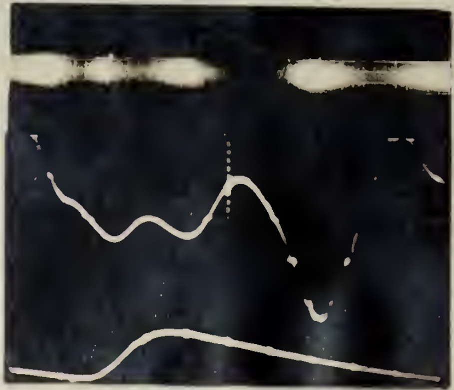
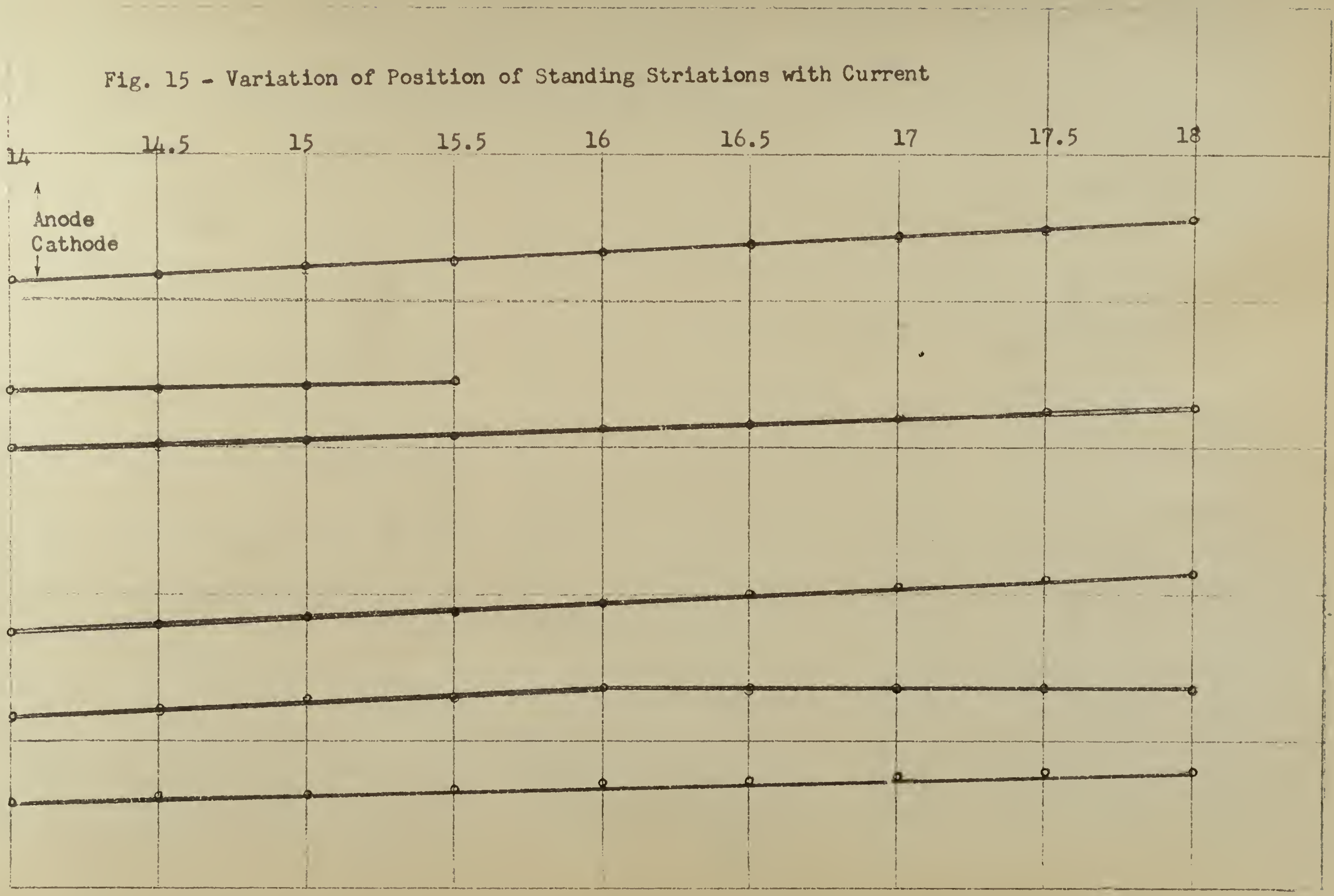


Fig. 14 - Oscilloscope and Associated Discharge Tube Photographs.

Fig. 15 - Variation of Position of Standing Striations with Current



was increased. Such an increase may be expected because from the standpoint of the developed AC voltage, the impressed DC potential is ground and all of the circuit potential drop must be developed across the load resistor.

In the range of currents from .4 ma to 2.4 ma an anomalous mode was observed with characteristics unlike those previously mentioned. The tube continued to glow for values below .4 ma, however no additional modes were observed.

Due to time limitations, a complete study of this mode, using different circuitry, pressure, etc., was not possible. However, some of the observations made are as follows:

a. Striations previously termed moving appeared in this mode to be pulsating or to have velocities greater than the available equipment could measure. Using the same techniques as previously mentioned for determining velocities, no motion was observed in the analysis of a 36 cm portion of the discharge tube. However, limitations of accuracy would permit velocities in excess of 25,000 meters per second to be undetectable.

b. The overall appearance of the positive column varied in that some portions of the discharge were more diffuse than others. Throughout the column standing striations were observed.

c. As was evidenced by photographs of the tube, each at a half milliampere current change, with total change from .4 ma to 2.4 ma, the relative positions of these standing striations were constant. This section was representative of the entire positive column. Separation of 1.47 cm was measured.

While separation remained constant, the overall pattern moved slightly toward the anode with increasing current in a manner similar to that shown in Fig. 15.

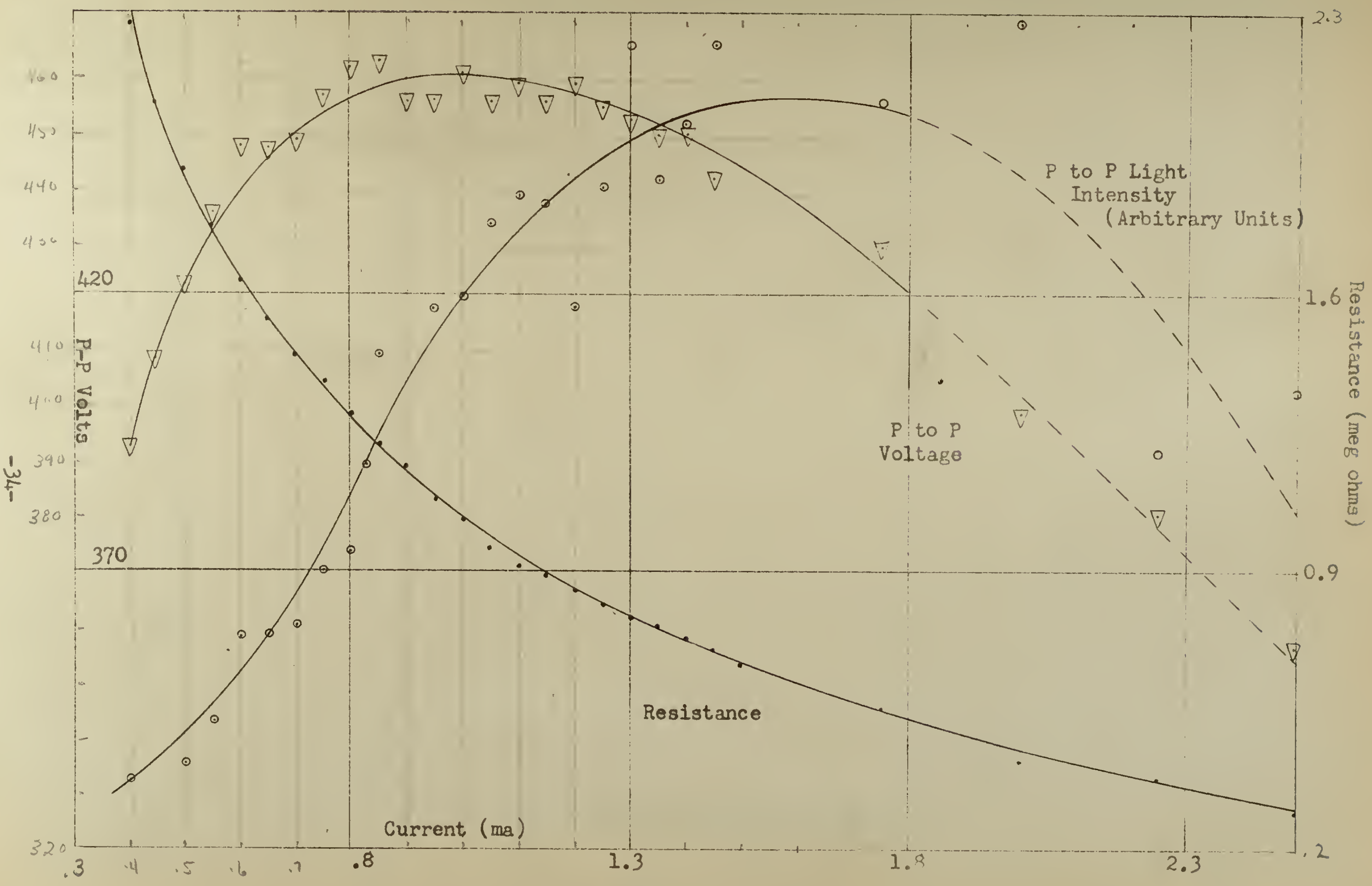


Fig. 16 - Plot of Anomolous Mode Characteristics

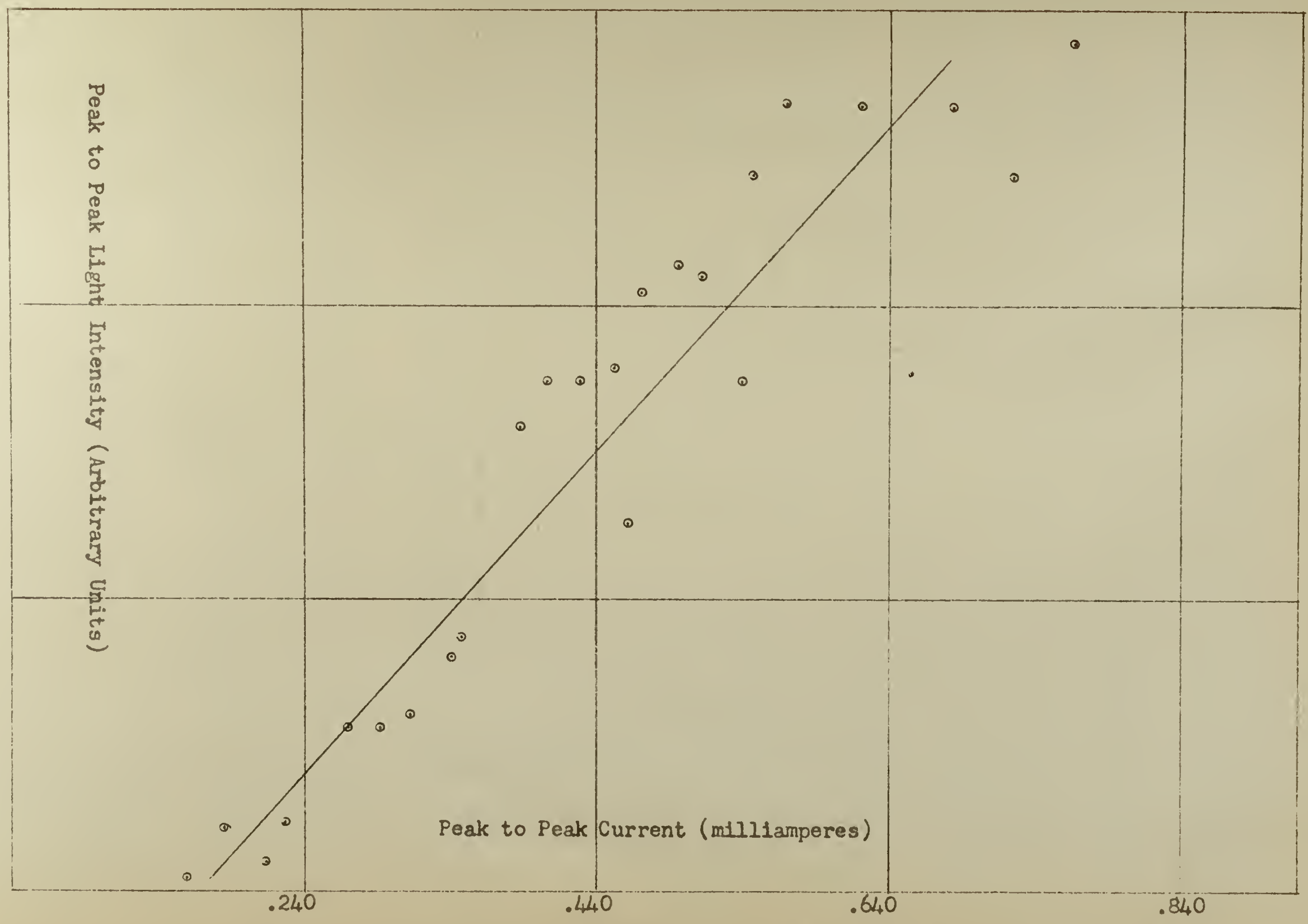


Fig. - 17- Plot of Peak to Peak Light Intensity Versus Peak to Peak Current

e. A plot of period and D.C. tube voltage versus current is shown in Fig. 16.

f. A plot of peak to peak voltage and peak to peak light intensity variations versus current is shown in Fig. ~~17~~. 16

g. This mode persisted when the center section was replaced by an identical section without probes.

h. A normal mode existed, with attending moving striations and peak to peak voltage oscillations of about 40 volts, at the upper current boundary of this anamolous mode, as shown in Fig. 7.

i. The possibility of feedback from the regulated power supply or other source was considered. In the range of frequencies encountered and with the isolating resistances utilized, capacitative feedback would require a feedback capacitor of 200 uuf, which is an order of magnitude higher than distributed capacitance of leads used. With all measuring equipment removed except the plate current milliammeter and with a 4 uf capacitance shunt across the power supply, the tube appearance of the tube was unaltered. With the addition of a VTVM (Hewlett-Packard 410B, input impedance 10 megohms with 1.3 uuf shunt) the mode was observed to exist unchanged with the peak to peak voltages reported.

j. The plot of A.C. peak to peak light intensity versus peak to peak A.C. current as is shown in Fig. 17 appears to be linear, over the range observed, and this relationship would indicate the absence of cumulative excitation and ionization.

CHAPTER IV

CONCLUSIONS

1. Discussion of Principal Results

There are investigators who believe that hydrogen is the only gas which will exhibit striated positive columns when extremely pure (26). With this in mind, perhaps, previous investigators utilizing this particular tube noted that the systems of striations observed appeared unusual (12).

A summary of the system of striations in Argon at 2 mm Hg which previous investigators have observed, and which have now been duplicated, follows:

a. At particular values of current, and external isolating resistance, visible standing striations will exist.

b. Moving striations have been observed which travel toward the cathode with an average velocity of 200 meters/sec. These moving striations speed up between standing striations and slow down in standing striations.

c. Higher energy wave lengths lead lower wave lengths in the positive striations.

d. Probes permanently inserted in the center section had marked local effects on the striated column. When the column was striated a standing striation existed on the anode side of each probe. Additionally, moving striations showed a marked decrease in velocity in approaching a probe in agreement with Oleson and Cooper (27).

e. Standing and moving striations are interrelated for moving striations seem not to exist without the standing striations. When standing striations were not present there was still random light

intensity travel which appeared to require only a grouping mechanism to become a moving striation.

In addition to the foregoing, an anomalous mode was observed which appeared to have standing striations without moving striations.

In view of the reproduction of the essential characteristics obtained by separate investigations on this particular discharge tube it is reasonable to assume that either the discharge system is not unusual or that some essential feature of the tube or external circuitry is responsible. Impurities cannot be ruled out completely, but in view of the painstaking effort to eliminate them, they seem unlikely. Permanently intruding probes were not responsible for the striation system, although they did have local effects. Lumped constants in the external circuitry had marked effects but do not appear to be responsible for the overall striation system.

Hysteresis appears to be a dynamic or transient phenomenon and is a function of cathode temperature. Multiplicity of modes in the steady state does not exist, providing sufficient time is allowed for equilibrium to be obtained.

2. Recommendations for Further Work

(1) Incorporate movable electrodes and probes in future tubes for greater versatility.

(2) Additional purification is obtainable with cataforesis and future discharge tube systems should incorporate this feature (28).

(3) To eliminate the possibility of non-steady state operation a thermocouple may be constructed in or on the cathode. Once steady state temperatures are determined, the waiting period for steady state operation can be eliminated.

(4) Incorporate some means of measuring dynamic pressure in order to determine any connection between pressure variation (if any) and other parameters as a striation passes a given point.

(5) The use of a cathetometer is necessary to obtain position accuracies necessary to detect zero velocities for periods of 10 micro-seconds. An alternative would be a coincidence circuit utilizing two photomultiplier tubes.

(6) Further investigation of the reported anomolous mode seems indicated.

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